FRED Reports

Fisheries Habitat Evaluation and Limnological Investigations of Big Lake, Ratz Harbor, Prince of Wales Island, Alaska
1989-1991

by
T. P. Zadina, M. H. Haddix and
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Number 124

Alaska Department of Fish & Game
Division of Fisheries Rehabilitation,
Enhancement and Development

Sikes Act Contract No. 43-0109-0-0741, Item #03

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Abstract

Big Lake was identified in 1988 by the U.S. Forest Service as a barriered lake system in need of bioenhancement. In 1989, the U.S. Forest Service contracted the Alaska Department of Fish and Game, FRED Division to assess the potential of the Big Lake system. Evaluation of the system was done in 1989 and 1991. In 1990, the U.S. Forest Service began construction on the fish pass below Big Lake. The fish pass was completed in 1991. Limnological studies in 1989 and 1991 indicated Big Lake nutrient supplies were normal for Southeast Alaska oligotrophic lakes. Macrozooplankton biomass in Big Lake was above average for this lake type. Based on these zooplankton densities Big Lake can potentially produce up to 224,000 threshold (2.2 g) size sockeye salmon (*Oncorhynchus nerka*) smolts. However, sockeye salmon fry densities varied greatly over the three brood years that were sampled. The age 1 sockeye salmon smolt population estimate was 70,584 for brood year 1988. However, the brood year 1989 and 1990 sockeye salmon smolt population estimates were less than 10,000 each year. The reduced production may be related to the partial barrier falls. However, this population may be overharvested in existing commercial fisheries which restricts the number of adults returning. Returning brood populations of sockeye salmon to Big Lake over the next five years will provide insight into future needs for bioenhancement of this system. Coho salmon (*Oncorhynchus kisutch*) populations in Big Lake do not appear to be affected by the partial barrier. Coho densities and size were very healthy. Steelhead trout (*Oncorhynchus mykiss*) populations were also found above the falls prior to fish pass construction.

Introduction

The U.S. Forest Service has embarked on a major program to enhance anadromous fish populations on the Tongass National Forest. A segment of the enhancement program considers systems with barriers to the upstream migration of anadromous fish. These systems have and are being considered for barrier modification or fish pass construction.

The Big Lake system is one such system. A fish pass allowing unimpeded upstream access over a barrier falls below Big Lake was completed by the U.S. Forest Service in 1991.

The initial habitat assessment survey of Big Lake was completed in July 1989. This survey revealed the presence of both juvenile sockeye and coho salmon in the system above the barrier falls. The presence of anadromous fish above the barrier prior to construction of the fish pass verified the falls were not a total barrier to upstream passage of either sockeye or coho salmon. The falls appear to be only a partial barrier and purely a function of stream discharge. The need for a bioenhancement program was in question and additional studies were initiated to estimate rearing densities of juvenile sockeye and coho salmon. These additional studies would explicitly define the rearing potential of the Big Lake system and further assess the need for bioenhancement. These studies were completed in September 1991. The results and discussion of these studies with recommendations are presented in this report.

Project Sponsorship -- The U.S. Forest Service, Thorne Bay Ranger District contracted the Alaska Department of Fish and Game, Fisheries Rehabilitation, Enhancement and Development (FRED) Division to assess the potential of the lentic habitat, above the barrier, to rear sockeye and coho salmon and develop a bioenhancement program from these findings through a Sikes Act Contract. This is the final report to the U.S. Forest Service fulfilling contract obligations for Sikes Act Contract number 43-0109-0-0741, Item #03.

Study Site Description -- Big Lake (132°39'W, 55°52'N) located ~80 km northwest of Ketchikan on the East Coast of Prince of Wales Island lies within the Tongass National Forest at an elevation of 55 m (Figure 1). Big Lake has a surface area of 90.5 ha (224 acres), a mean lake depth of 14.7 m, a maximum depth of 35 m, and a total volume of 13.33×10^6 m^3 (Figure 2).

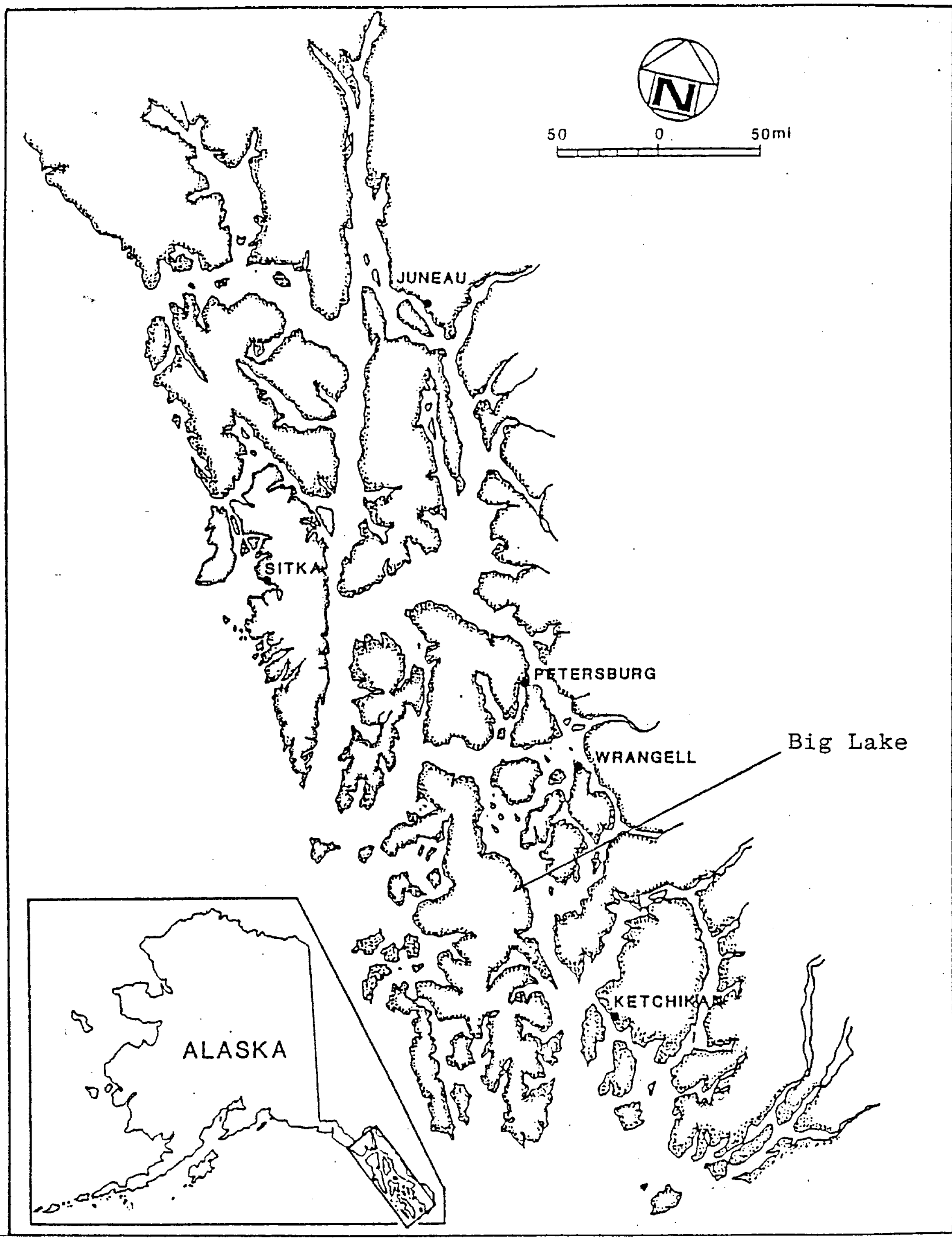
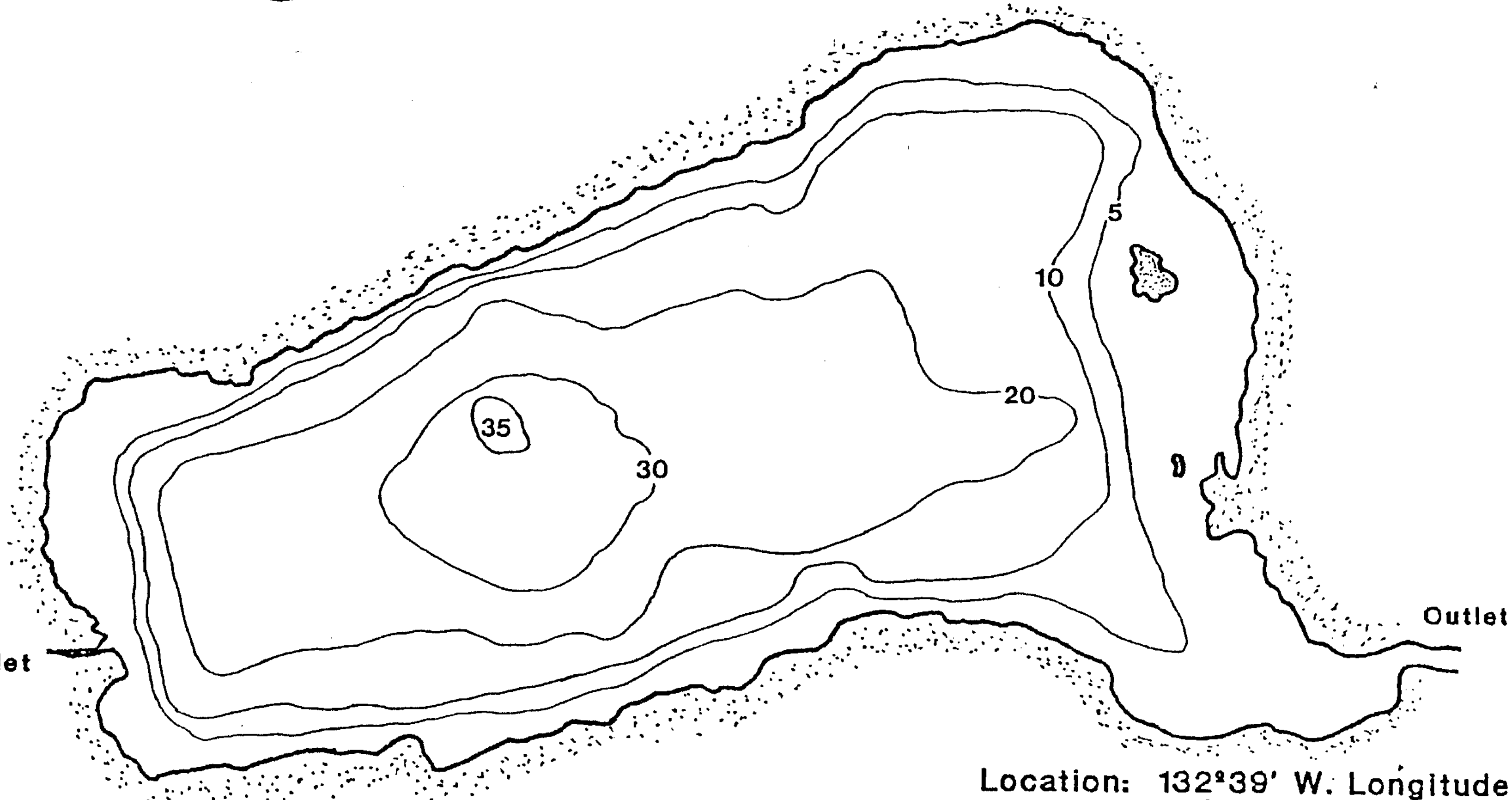


Figure 1. The geographic location of Big Lake, Ratz Harbor within the State of Alaska, and relative to cities within Southeast Alaska.

Big Lake - Ratz Harbor



(Depths in meters)
Scale: 1 in = 219 m

Location: 132°39' W. Longitude
55° 52' N. Latitude
Area: 90.5 ha / 224 acres
Volume: 13.33 million cu.m.
Maximum Depth: 35 m
Mean Depth: 14.7 m

Created by T. Zadina; ADF&G, FRED Limnology, 1991

Figure 2. Morphometric map of Big Lake, Ratz Harbor, Southeast Alaska.

Methods and Materials

Lake Design

A bathymetric map was constructed from numerous depth transects taken with a Simrad EY-M recording fathometer.

Limnological Sampling

Sampling to define lake productivity and juvenile sockeye carrying capacity was conducted on 1 August 1989, 9 May 1991, 30 July 1991 and 13 September 1991. Limnological parameters were sampled at one station located at the deepest area (35m) of the lake. In addition to obtaining physical data (e.g., light penetration, temperature profiles and dissolved oxygen levels), water quality and biological samples were collected. Analysis of these samples was accomplished by the ADF&G, FRED Limnology Laboratory in Soldotna, Alaska.

Physical Parameters -- Measurements of light penetration (footcandles) were recorded at 0.5 m intervals from the surface to a depth equivalent to one percent of the subsurface light reading using a Protomatic submarine photometer. The euphotic zone depth (EZD), the depth to which 1% of the subsurface light [photosynthetically available radiation (400-700 nm)] penetrates (Schindler 1971), was calculated as the y-intercept derived by regressing depth against the logarithm (ln) of the percent subsurface light. Euphotic volume (EV) is the product of the euphotic zone depth (EZD) and the lake surface area and represents the volume of water capable of photosynthesis. Secchi disk (SD) transparency was determined by recording the depths at which the disk becomes invisible upon descent and visible upon ascent. Temperatures and dissolved oxygen levels were recorded at 1 m intervals from the lake surface to the bottom using a YSI model 58 meter.

Water Quality -- Water quality samples were collected from the epilimnion at the 1 m depth and the mid-hypolimnion using a Van Dorn sampler. Eight liters of water were collected from each depth, stored in pre-cleaned polyethylene carboys, transported to Ketchikan, and then filtered or preserved for laboratory analysis. Separate subsamples from each carboy were: 1) refrigerated for general tests and metals; 2) frozen for nitrogen and phosphorus analysis; and 3) filtered through a Whatman 4.7 cm GFF glass fiber filter and frozen for analysis of dissolved nutrients (Koenings, et al. 1987).

Phytoplankton -- Samples for the analysis of the algal pigment chlorophyll a (chl a) were prepared by filtering 1-2 ℓ of lake water through a Whatman 4.7 cm GFF glass fiber filter to which 1-2 mℓ of 1N magnesium carbonate were added prior to completion. Filters were stored frozen in individual plexiglas holders until analyzed.

Zooplankton -- Replicate bottom to surface vertical zooplankton tows were taken using a 0.5 m diameter, 153 μm mesh, 1:3 conical net. The net was pulled at a constant speed ($\sim$0.5 m•sec^{-1}), rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings, et al. 1987).

Laboratory Analysis

General Water Quality -- Conductivity (temperature compensated to 25°C) was measured using a YSI model 32 conductance meter, and the pH was measured with an Orion 399A ionanalyzer following standard calibrations. Alkalinity was determined by sulfuric acid (0.02N) titration to a pH of 4.5 (APHA 1985). Turbidity, expressed in nephelometric turbidity units (NTU) was determined using a DRT-100 turbidimeter. Water color was determined on a filtered sample by measuring the spectrophotometric absorbance at 400 nm and converting to equivalent platinum cobalt (Pt) units (Koenings, et al. 1987).

Metals -- Calcium and magnesium were determined from separate EDTA (0.01N) titrations after Golterman (1970). Total iron was determined by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion after Strickland and Parsons (1972).

Nutrients -- Filterable reactive phosphorus (orthophosphate) was determined using the molybdenum-blue method as modified by Eisenreich, et al. (1975). Total and total filterable phosphorus utilized the same procedure following acid-persulfate digestion. Total ammonia (NH_3 + NH^+_4) was determined using the phenolhypochlorite procedure; and nitrate (NO^-_3) + nitrite (NO^-_2) were determined as nitrite following cadmium reduction and diazotization with sulfanilamide after Stainton, et al. (1977). Total Kjeldahl nitrogen (TKN) was determined as ammonia after sulfuric acid block digestion (Crowther, et al. 1980). Total nitrogen was calculated as the sum of TKN and nitrate + nitrite. Reactive silicon was determined using the ascorbic acid reduction to molybdenum-blue methodology after Stainton, et al. (1977).

Phytoplankton -- Phytoplankton biomass (primary production) was estimated from the algal pigment chlorophyll a (chl a). Chl a was extracted from glass fiber filters after homogenizing the filters in 90% acetone (Koenings, et al. 1987). Chl a concentrations (corrected for inactive phaeophytin) were then determined using the direct fluorometric procedure of Strickland and Parsons (1972) with dilute acid (0.02N HCl) addition after Reimann (1978).

Zooplankton -- *Daphnia* sp. were identified according to Brooks (1957) and copepods were identified after Wilson (1959) and Yeatman (1959). Zooplankton were enumerated from three separate 1 mℓ subsamples taken with a Hensen-Stemple pipet and placed in a 1 mℓ Sedgewick-Rafter counting chamber. Zooplankton body sizes from thirty organisms of each species were measured to the nearest 0.01 mm along a transect in each of the 1 mℓ subsamples using a calibrated ocular micrometer. Zooplankton biomass was estimated using species-specific dry weight vs. zooplankter length regression equations (Koenings, et al. 1987).

Juvenile Fisheries Assessment

Sockeye Salmon Production

Hydroacoustic Surveys -- Juvenile sockeye salmon population and distribution analysis in Big Lake were conducted using a Simrad EY-M (70 kHz single beam system) scientific echosounder with a 22° wide beam transducer. Sampling design for Big Lake uses five stratified, randomly chosen orthogonal transects across the lake. Fish signals were recorded electronically using a Technics SV-MD1 digital audio tape (DAT) cassette recording system. The recorded hydroacoustic tapes were sent to Biosonics, Inc. for analysis. Analysis was done using echo counting techniques and sample volumes by duration-in-beam measurement procedures by Thorne (1988). Mid-water trawl sampling was used to determine and verify fish species composition. A 2 m x 2 m elongated trawl net was used for sampling. Trawl depths were determined by fish densities and distributions throughout the lake based on observations during the hydroacoustic survey portion. Fish captured were preserved in 10% buffered formalin, and measured after six weeks to the nearest millimeter and weighed to the nearest 0.1 g. In addition, a scale smear was taken from each fish, affixed to a 2.5 cm x 7.5 cm glass slide, and aged using a television / video linked microscope. Hydroacoustic surveys with corresponding mid-water trawls were accomplished at prudent dates to acquire three years of sockeye smolt outmigrant data in Big Lake. The corresponding dates for this work were 31 July 1989, 13 May 1991 and 8 July 1991.

Coho Salmon Production

Fish were captured using Gee minnow traps baited with treated salmon eggs. Six traps were fish four hours each around the littoral area of the lake and in the inlet and outlet streams. All coho salmon were preserved in 10% buffered formalin and later analyzed like the sockeye fry previously mentioned. All trout and char were anesthetized using MS-222, measured to the nearest millimeter and subsequently released.

Results and Discussion

Limnological Assessment

Light Penetration -- During 1989 and 1991, the euphotic zone depth ranged from 3.2 m to 6.0 m and averaged 4.6 m (Table 1). Based on the average EZD (4.6 m), the euphotic volume (EV) of Big Lake was estimated at 4.2 x 10^6 m^3 or 4.2 EV units which comprises

~32% of the total lake volume. Secchi disk (SD) transparency ranged from 2.38 m to 4.5 m and averaged 3.34 m.

Temperature and Dissolved Oxygen Regimes -- Big Lake follows a standard summer stratification with summer surface temperatures (Table 2) reaching 18.9°C in 1989 and 15.3°C in 1991. Temperatures cooled rapidly down to 10-15 m to 6°C and then remained fairly constant to the bottom. Thus during summer stratification the surface to ~10 m stratum was defined as the epilimnion which comprised 52.3% of the total lake volume. The thermocline extended from ~10-20 m, and the hypolimnion was formed at depths >20 m. Dissolved oxygen (D.O.) concentrations (Table 3) ranged between 9 and 12 $mg \bullet \ell^{-1}$ (85->100% saturation) within the epilimnion, decreased slightly within the hypolimnion and dropped dramatically near the bottom (Figure 3). The lower D.O. concentrations near the bottom were confined to <1% of the total lake volume and thus, do not represent a serious concern.

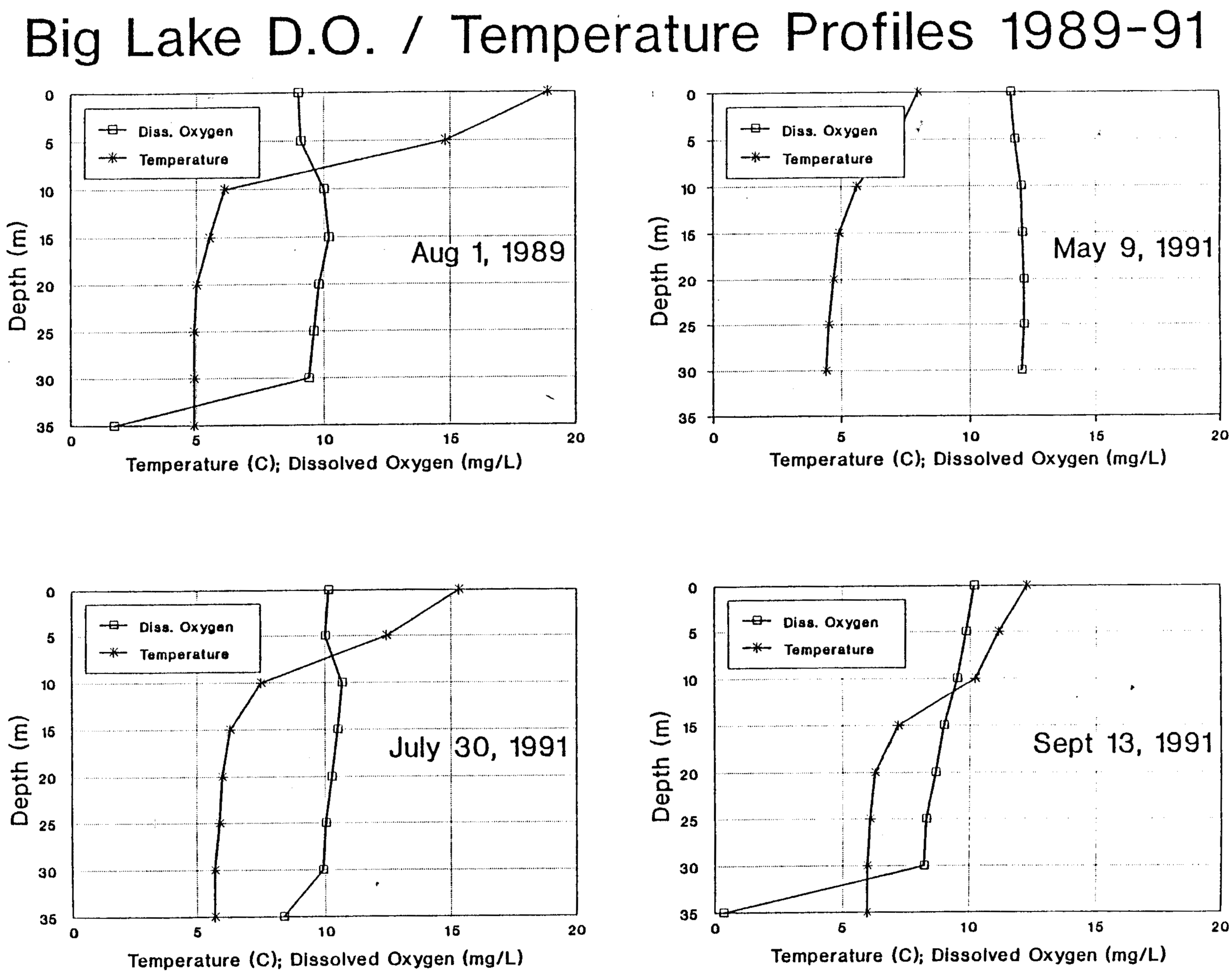


Figure 3. Seasonal temperature and dissolved oxygen profiles in Big Lake during 1989 and 1991.

Table 1. Big Lake light intensity profiles for 1 August 1989 to 13 September 1991.

Light Intensity Levels by percentage

Depth (m)	1989 1 Aug	1991 9 May	1991 30 July	1991 13 Sept
Above surface	230.0	242.9	192.3	265.8
5cm	100.0	100.0	100.0	100.0
0.5m	65.0	66.7	48.1	45.6
1.0	41.0	34.3	23.1	15.2
1.5	28.0	15.2	14.2	7.7
2.0	18.0	7.6	9.6	3.4
2.5	14.0	4.8	5.2	1.8
3.0	8.8	3.2	3.7	1.1
3.5	5.7	2.2	2.7	0.6
4.0	4.0	1.4	1.7	
4.5	2.8	0.9	1.2	
5.0	2.0	0.8		
5.5	1.5			
6.0	1.0			

Table 2. Big Lake temperature profiles for 1 August 1989 to 13 September 1991.

	Temperature (°C)			
Depth (m)	1989 1 Aug	1991 9 May	1991 30 July	1991 13 Sept
1.0	18.9	8.0	15.3	12.2
2.0	18.9	7.9	15.2	12.1
3.0	18.2		14.1	11.7
4.0	16.8	7.5	13.4	11.5
5.0	14.8		12.4	11.1
6.0	13.8	6.8	11.3	11.0
7.0	10.1		10.9	
8.0	8.1	6.0	8.8	10.6
9.0	7.9			10.4
10.0	6.1	5.6	7.5	10.2
12.0	5.9	5.4	6.8	9.1
14.0	5.5	5.0	6.4	7.7
16.0	5.4	4.9	6.3	6.8
18.0	5.1	4.7	6.1	6.4
20.0	5.0	4.7	6.0	6.3
25.0	4.9	4.5	5.9	6.1
30.0	4.9	4.4	5.7	6.0
35.0	4.9	4.4	5.7	6.0

Table 3. Big Lake dissolved oxygen profiles for 1 August 1989 to 13 September 1991.

	Dissolved Oxygen ($mg \bullet \ell^{-1}$)			
Depth (m)	1989 1 Aug	1991 9 May	1991 30 July	1991 13 Sept
1.0	9.00	11.60	10.15	10.15
2.0	9.05	11.60	10.12	10.08
3.0	9.00		9.99	9.93
4.0	8.90	11.70	9.95	9.83
5.0	9.10		10.00	9.83
6.0	9.00	11.80	10.09	9.73
7.0		10.23	9.66	
8.0	9.60	11.90	10.59	9.73
9.0		10.64	9.66	
10.0	10.00	12.00	10.66	9.51
12.0	10.20	12.00	10.68	9.28
14.0	10.20	12.10	10.53	9.07
16.0	10.20	12.00	10.45	8.93
18.0	10.00	12.10	10.31	8.90
20.0	9.80	12.10	10.27	8.68
25.0	9.60	12.10	10.03	8.32
30.0	9.40	12.00	9.91	8.25
35.0	1.70		8.37	0.32

General Water Quality -- Big Lake is a soft water system as evidenced by low conductivities ranging from 28 - 32 $\mu mhos \bullet m^{-1}$ (Table 4). Moreover, alkalinities varied from 7.0 - 12.0 $mg \bullet \ell^{-1}$ (as $CaCO_3$) which indicates moderately low levels of inorganic carbon (Wetzel 1975). The pH was slightly acidic and ranged from 6.3 - 7.1 units. Turbidities in Big Lake were very low and ranged from 0.1 - 1.2 NTU; whereas, color ranged from 24 - 41 Pt units which characterizes Big Lake as a stained system (Koenings and Edmundson 1991).

Metals -- Calcium levels in Big Lake are considered low to moderate (3.4 - 5.2 $mg \bullet \ell^{1}$) for oligotrophic Alaskan lakes (Table 4). Magnesium levels were also low ranging from <0.2 - 0.8 $mg \bullet \ell^{-1}$. Unlike clearwater lakes, which typically exhibit iron levels <20 $\mu g \bullet \ell^{-1}$ (Stumm and Lee 1960), concentrations with the epilimnion and hypolimnion in Big Lake ranged from 54 - 280 $\mu g \bullet \ell^{-1}$, and averaged 159 $\mu g \bullet \ell^{-1}$ which is characteristic of organically stained lakes (Koenings 1976).

Nutrient Levels -- During 1989 and 1991, total phosphorus (TP) levels in Big Lake ranged from 3.6 - 6.0 $\mu g \bullet \ell^{-1}$ and averaged 4.9 $\mu g \bullet \ell^{-1}$ within the epilimnion (Table 4). Total filterable (TFP) and filterable reactive phosphorus (FRP) levels within depth averaged 3.1 and 2.7 $\mu g \bullet \ell^{-1}$, respectively (Table 4).

Ammonia nitrogen levels (Table 4) were relatively low in the epilimnion with concentrations ranging from 3.0 - 5.2 $\mu g \bullet \ell^{-1}$ and averaged 3.7 $\mu g \bullet \ell^{-1}$. The hypolimnion levels were higher with a range of 4.5 - 23.1 $\mu g \bullet \ell^{-1}$ and averaged 15.6 $\mu g \bullet \ell^{-1}$. Nitrate + nitrite levels within the hypolimnion averaged ~55 $\mu g \bullet \ell^{-1}$, but epilimnetic concentrations decreased to <11 $\mu g \bullet \ell^{-1}$ during the summer which signals a nitrogen deficit. Total Kjeldahl nitrogen (TKN) levels (equivalent to ammonia + organic nitrogen) were higher in 1989 than 1991. The 1989 summer sample averaged 100 $\mu g \bullet \ell^{-1}$ and the summer 1991 sample averaged 69 $\mu g \bullet \ell^{-1}$. Total nitrogen (TN) levels within the epilimnion were lowest in the summer of 1991 compared to the spring and fall ranging from 88 - 124 $\mu g \bullet \ell^{-1}$ and averaged 107 $\mu g \bullet \ell^{-1}$ (Table 4).

Reactive silicon (Si) levels remained relatively constant throughout both sampling years. Concentrations averaged 1168 $\mu g \bullet \ell^{-1}$ (Table 4).

Table 4. Summary of General Water Quality parameters including pH, specific conductance, alkalinity, turbidity, color, metal concentrations, nutrient concentrations, and algal pigments within the epilimnion (1m) and hypolimnion of Big Lake, 1989 and 1991.

Date	1 Aug 1989		9 May 1991		30 July 1991		13 September 1991	
Parameter Depth	1 m	Hypolimnion	1 m	Hypolimnion	1 m	Hypolimnion	1 m	Hypolimnion
pH (units)	7.1	6.3	6.6	6.5	7.0	6.4	6.8	6.4
Conductivity (μmhos$\bullet$cm^{-1})	32	28	29	29	32	30	29	28
Alkalinity (mg$\bullet\ell^{-1}$)	12.0	8.0	9.0	10.5	9.0	7.0	10.0	9.0
Turbidity (NTU)	1.0	0.6	0.6	0.5	0.4	0.6	0.1	1.2
Color (Pt units)	24.5	31.2	24.0	26.0	24.0	26.0	41.0	24.0
Calcium (mg$\bullet\ell^{-1}$)	NA	5.2	3.4	3.4	4.6	4.6	4.8	4.8
Magnesium (mg$\bullet\ell^{-1}$)	NA	<0.2	0.6	0.6	0.8	<0.2	0.5	0.5
Total iron (μg$\bullet\ell^{-1}$)	75	220	148	180	54	142	169	280
Total-P (μg$\bullet\ell^{-1}$)	3.6	4.9	6.0	4.2	4.3	4.2	5.6	5.6
TFP (μg$\bullet\ell^{-1}$)	2.4	3.2	3.3	3.3	3.1	3.0	3.7	3.3
FRP (μg$\bullet\ell^{-1}$)	1.9	2.8	2.8	3.3	2.6	2.4	3.3	2.3
TKN (μg$\bullet\ell^{-1}$)	96.9	103.6	66.7	56.5	76.9	61.1	89.7	72.8
Total N (μg$\bullet\ell^{-1}$)	103.9	160.1	113.7	112.6	87.8	113.2	124.6	128.3
Ammonia (μg$\bullet\ell^{-1}$)	5.2	23.1	3.0	4.5	3.5	14.3	3.0	20.5
Nitrate + Nitrite (μg$\bullet\ell^{-1}$)	7.0	56.5	47.0	56.1	10.9	52.1	34.9	55.5
Reactive silicon (μg$\bullet\ell^{-1}$)	1149	1161	1146	1194	1177	1119	1288	1107
Chl a (μg$\bullet\ell^{-1}$)	0.66	0.03	0.57	0.03	1.31	0.03	0.93	0.07
Phaeo a (μg$\bullet\ell^{-1}$)	0.19	0.13	0.14	0.09	0.21	0.23	0.22	0.16

/a NA indicates not available.

Phytoplankton -- During 1989 and 1991 chl a concentrations within the epilimnion ranged from 0.57 - 1.31 $\mu g \bullet \ell^{-1}$ and averaging 0.87 $\mu g \bullet \ell^{-1}$ (Table 4).

Zooplankton Abundance and Body Size -- The total macrozooplankton community in Big Lake was comprised of two species of copepods and six species of cladocerans (Table 5). The copepod community consisted of *Cyclops* sp. and *Diaptomus* sp. The cladocerans were represented in abundance primarily by *Bosmina* sp.; however, *Daphnia rosea, Holopedium* sp., *Daphnia longiremis, Polyphemus* sp. and *Scapholeberis* sp. are also present. The total macrozooplankton density ranged from 287,827$\bullet m^{-2}$ in 1989 to 223,807$\bullet m^{-2}$ in 1991.

As a group, the copepods comprised a larger population percentage in the spring (~81%) of 1991 than in late summer (~28%). *Cyclops* was the numerically dominant species. The densities of *Cyclops* ranged from 56,037 - 173,714$\bullet m^{-2}$. The weighted mean body sizes of *Cyclops* and *Diaptomus* was 0.82 and 1.37 mm, respectively (Table 5).

Within the cladoceran community, *Bosmina* was by far the most abundant species with densities ranging from 26,745 - 157,922$\bullet m^{-2}$. The highest density of *Bosmina* occurred during August 1989. *Bosmina* comprised a larger percentage in late summer (~54%) of the total macrozooplankton population than in spring (~12%). However, the mean body sizes remain consistently small throughout the growing season. With a mean body size of 0.37 mm they are considered below the 0.40 mm minimum threshold size for elective feeding by sockeye salmon fry (Koenings and McDaniel 1983; Kyle, et al. 1988). Even though densities remain high this suggests heavy predation of *Bosmina* above the threshold size. *Daphnia rosea* is the second most abundant cladoceran with densities ranging from 5,434 - 31,415$\bullet m^{-2}$. The mean body size ranged from 0.74 - 0.79 mm. *Holopedium* is the next most abundant with densities ranging from 1,019 - 15,283$\bullet m^{-2}$. The mean body size ranged from 0.40 - 0.80 mm. This species is only found during mid-summer sampling. *Daphnia longeremis* was identified during all sampling periods. The densities for this species ranged from 1,274 - 14,603$\bullet m^{-2}$ and had a mean body size range of 0.82 - 0.84 mm. The other two cladocerans were only present in the August 1989 sample in very low densities of 425$\bullet m^{-2}$ (Table 5).

Table 5. Macrozooplankton densities and body size from Big Lake from samples taken at 32m depth on 1 August 1989 and 9 May, 30 July and 13 September 1991.

Species present	Macrozooplankton Density (#•m^{-2})			
	8/01/89	5/09/91	7/30/91	9/13/91
Cyclops	75,989	173,714	102,564	56,037
Bosmina	157,922	26,745	108,677	109,356
Diaptomus	5,094	1,019	340	
Daphnia l.	1,274	14,264	6,113	14,603
Daphnia r.	31,415		5,434	22,075
Holopedium	15,283		1,019	
Polyphemus	425			
Scapholeberis	425			
Totals	**287,827**	**215,742**	**223,807**	**202,411**

Species	Mean Body Size (mm)			
	8/01/89	5/09/91	7/30/91	9/13/91
Cyclops	0.83	0.56	0.82	0.80
Bosmina	0.36	0.43	0.34	0.34
Diaptomus	1.28		1.42	1.42
Daphnia l.	0.82	0.84	0.84	0.82
Daphnia r.	0.79		0.77	0.74
Holopedium	0.80		0.40	
Polyphemus	0.52			
Scapholeberis	0.44			

Zooplankton Biomass -- The total weighted macrozooplankton biomass in Big Lake varied significantly between 1989 and 1991 averaging 601 and 328 mg•m^{-2} respectively (Table 6). In 1989, *Cyclops* populations comprised ~31% of the total biomass and ~53% of the total biomass in 1991. *Bosmina* remained fairly constant in both years with 31% in 1989 and 28% of the total biomass in 1991. *Holopedium* made a drastic change comprising ~17% in 1989 and dropping to less than 1% in 1991.

Table 6. Relative biomass of macrozooplankton from Big Lake for 1989 and 1991.

	Weighted Biomass (mg•m^{-2})	
Species	1989	1991
Cyclops	188.81	175.10
Bosmina	186.57	90.74
Diaptomus	42.39	5.24
Daphnia l.	3.50	35.95
Daphnia r.	79.29	20.33
Holopedium	101.08	0.41
Totals	601.64	327.77

Juvenile Fisheries Data

Sockeye Salmon Production -- Population estimates of sockeye based on hydroacoustic surveys and trawl catch samples (Table 7) were used to estimate three brood years. Brood year 1988, Age 0 1989 sockeye fry population was estimated to be 100,835. Mean length and weight for this age class was 45.1 mm and 0.98 g respectively in July. The 1989 brood year, 1991 Age 1 smolt population was estimated to be 10,375 in May. Mean length and weight for this age class was 64.5 mm and 2.75 g respectively. The 1990 brood year fry were evaluated as Age 0 in July 1991. The fry population estimate for this brood year was 4,485 with a mean length of 33.7 mm and mean weight of 0.37 g. The projected smolt populations are presented in Table 8.

Table 7. Sockeye salmon population estimates, mean size and age composition from hydroacoustic estimates and trawl analysis for July 1989, May 1991 and July 1991 at Big Lake.

Date	Age	n	Mean Length (mm)	Mean Weight (g)	Population Estimate
7/31/89	0	15	45.1	0.98	100,835
5/13/91	1	2	64.5	2.75	10,375
7/08/91	0	3	33.7	0.37	4,485
	1	7	75.0	4.51	10,465

Table 8. Big Lake projected sockeye salmon smolt estimates based on 1989 to 1991 hydroacoustic and trawl samples.

Year	Age	Smolt Estimate	Estimated Adults Produced
1990	1	70,584	8,470
1991	1	0*	0
1992	1	10,465	1,256

* Estimated no smolt produced this year class due to total holdover of Age 1 fry from May to July surveys.

Sockeye Salmon Rearing Capacity Evaluation -- Potential sockeye salmon smolt production was estimated using both an euphotic volume model (Koenings and Burkett, 1987) and a zooplankton biomass model (Barto and Koenings, 1990) with corresponding data collected at Big Lake.

Koenings and Burkett (1987) established a relationship between EV and sockeye salmon production. The EV model yields a maximum of 23,000 Age-1 threshold size (2.2 g) smolt per EV unit. The EV model yields an 11,290 Age-1 optimum size (4.5 g) smolt. The EV model for Big Lake with 4.2 EV units would produce 96,600 threshold size or 47,418 optimum size sockeye smolt (Table 9).

Barto and Koenings (1990) established a biological relationship between zooplankton standing crop and sockeye salmon production. This model uses current biological trends found in each lake. Based on the zooplankton biomass this model still uses the threshold size (2.2 g) and optimum size (4.5 g) smolt production yields. The results of this analysis are presented in Table 9.

Table 9. Estimated Potential Smolt Production of Big Lake comparing the Euphotic Volume and Zooplankton Biomass Models using mean Euphotic Zone Depth and zooplankton densities from samples taken in 1989 and 1991.

Year	Seasonal Mean Zooplankton Density (#•m^{-2})	Seasonal Mean Zooplankton Biomass (mg•m^{-2})	Potential Threshold Smolt (2.2 g) Production	Potential Optimum Smolt (4.5 g) Production
1989	287,827	602		
1991	213,987	328		
Mean	250,907	465	224,216	109,617
EV Model		4.2 EV units	96,600	47,418

A comparison of the Big Lake zooplankton biomass relative to other lakes in Southern Southeast Alaska indicates that Big Lake secondary production levels are high (Table 10).

Table 10. Comparison of seasonal mean macro-zooplankton densities and biomass of Big Lake to other sockeye salmon nursery lakes (*) and other non-anadromous lakes (#) in southern Southeast Alaska.

Lake	Years Sampled	Macro-zooplankton Density ($\#\bullet m^{-2}$)	Biomass ($mg\bullet m^{-2}$)	Comments
Orchard (#)	89	262,778	821	
Margaret (*)	87 & 89	233,407	643	
Hugh Smith (*)	81 - 84	304,771	548	Fertilized
Heckman (*)	87 - 88	322,530	475	
Hugh Smith (*)	85 - 87	233,570	474	Post-Fertilize
Big (Ratz Hbr)(*)	**89 & 91**	**250,907**	**465**	
Woodpecker (#)	86	59,911	431	
McDonald (*)	82 - 90	108,239	351	Fertilized
Dog Salmon (*)	89	149,855	295	
Mary (O.Frnks)(#)	89	5,945	263	
Bakewell (*)	84, 85, 89	163,690	267	
Old Franks (#)	89	18,365	236	
Klawock (*)	86 - 87	113,262	212	
Patching (#)	87	82,125	212	Pre-stocking
Upper O.Franks(#)	89	36,650	210	
McDonald (*)	81	83,281	186	Pre-fertilize
Badger (*)	85 - 89	80,549	168	Fry stocked
Patching (#)	88	48,536	166	Fry stocked
Salmon(Karta)(*)	84 - 89	56,547	161	
Eagle (#)	89	48,311	150	
Ward (*)	89	156,648	136	
Virginia (*)	86 & 88	40,946	111	Pre-stocking
Virginia (*)	89 - 90	37,950	93	Fry stocked

Coho Salmon Production -- Fry trapping on 31 July 1989 resulted in the capture of coho salmon juveniles throughout Big Lake. An estimated 2.3 coho per trap per hour were captured during a four hour set. Age 0 coho comprised 27% of the sample and had a mean length and weight of 49.8 mm and 1.63 g, respectively. Age 1 coho comprised 73% of the sample and had a mean length and weight of 89.5 mm and 10.40 g, respectively.

Other Fisheries Production -- During fry trapping operations numerous other species were captured. The most abundant species captured was Dolly Varden char (*Salvelinus malma*). All Dolly Varden captured had a length range of 40 - 80 mm with a mean length of 60 mm. Coastal cutthroat trout (*Oncorhynchus clarki spp.*) captured ranged in length from 75 - 205 mm and had a mean length of 149 mm. One steelhead (*Oncorhynchus mykiss*) juvenile was also captured and had a mean length of 75 mm.

Discussion

The estimated potential sockeye smolt production for Big Lake, based on euphotic volume and estimated seasonal mean zooplankton production from 1989 and 1991 is 96,600 - 224,216 threshold size 2.2g sockeye salmon smolt. Based on standard survival assumptions this estimated sockeye smolt production would result in 11,592 - 26,905 adult sockeye of which 40% would be needed for escapement and 60% would be the harvestable surplus. The current reduced production may be related to the partial barrier which is being enhanced. However, this population may be over harvested in current commercial fisheries which restricts the number of adults returning.

In the 13 May 1991 mid-water trawl sample two kokanee were also captured. This resulted in an estimated kokanee population estimate of 10,375. Although no studies were conducted to define the status of the cutthroat trout populations, their presence could have some minor impacts on the production of anadromous sockeye salmon smolt. The effect of the kokanee population would probably be insignificant since the zooplankton densities used in estimating production are preyed upon by the kokanee population and thus are already decreased by their predation. The impact of predation by cutthroat trout is unknown; further studies at Margaret Lake will provide us insight into this factor.

There are two options for bioenhancement of the Big Lake sockeye population. The first being no action and allow the present natural population to increase over time with the fish ladder installed. The second is to plant sockeye fry into the lake in numbers to bring the lake up to its maximum rearing potential. This option would require the use of Big Lake system sockeye stocks, and egg takes would have to occur within the system. Incubation of eggs could take place at Beaver Falls Central Incubation Facility with release of the sockeye fry back to Big Lake. With the ladder functional, continued monitoring of adult returns should be done. Returning brood populations of sockeye salmon to Big Lake over the next five years will provide insight into future needs for bioenhancement of this system.

Current coho salmon and steelhead trout populations in this system will utilize the habitat above the partial barrier since populations of both were found above the falls prior to the ladder.

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